Elastic Modeling Initiative, Part I: Objectives

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Summary

The effects of elastic and converted waves are a significant concern in many exploration settings, and, if they are not adequately accounted for in processing, they can become misleading artifacts. More importantly, however, there is a tremendous amount of information, especially in pre-stack seismic data, that acoustic wave methods are not appropriate for, and thus can not extract. Building on the successful completion of the 3-D SEG/EAGE modeling effort, an "Elastic Modeling Initiative" seeks to better understand elastic and converted wave modes and their effects on seismic exploration efforts. This initiative would study geological and reservoir parameters to determine how best to take advantage of elastic waves and how to mitigate their potential negative effects. Since this initiative will potentially have a long lasting impact on the geophysical community this paper is intended to both inform those who are interested and to seek critical peer guidance and review.

Introduction

Studies of elastic (and acoustic/elastic converted wave) phenomena have shown that the contributions of these waves can be strong in some situations. Salt bodies can produce particularly strong conversions between acoustic and elastic waves (Ogilvie and Purnell, 1996; Kessinger and Ramaswamy, 1996). With salt and salt-related exploration situations becoming more common, it is important to understand and exploit elastic wave effects. The increasing acquisition of multi-component seismic data provides additional impetus. Recent advances in acquisition (such as ocean-bottom cables and 4-C), provide opportunities to exploit shear wave information in marine environments to a greater extent than ever before. In both these situations, understanding of elastic and converted wave effects may significantly improve the interpretation of the resulting data and images.

New exploration plays are typically located in areas with complex geological settings which are difficult to image seismically. Thus, making the most of the seismic data and reliably interpreting it is an increasingly complicated, but important, task.

In field development applications, building a reliable reservoir model is a key step, and must fully utilize the available seismic, log and rock physics data. Reservoir properties for such models heavily rely on the relationships between the rock parameters and the corresponding seismic response. The acoustic response of simple structures is readily modeled and examples are available for routine use in many practical applications, such as AVO. The elastic response for complex structures is more difficult to model and examples are not readily available.

An Elastic Modeling Initiative is being undertaken to improve understanding of how elastic waves are affected by geologic factors, data acquisition, and data processing. The initiative will also study how they may affect the reliability of seismic imaging and the accuracy of reservoir models. This initiative is an extension of the large SEG/EAGE numerical modeling project, which focused on acoustic modeling

The SEG/EAGE Modeling Project

This project is briefly summarized here, for more details refer to Aminzadeh et al., (1997), or Aminzadeh et al., (1996).

The SEG/EAGE modeling project was a multi-year collaboration between researchers from the oil and gas industry and government laboratories. The project goals were to define complex geologic models and compute synthetic seismic data from them.

The two models designed for this effort were of salt and overthrust structures. The salt model includes many features that are found in salt structures in the Gulf of Mexico. Among them are: a horizontally extensive salt body with a plunging stock, a secondary reactivation crest, one broad, low relief flank, another flank that is faulted, and has a minor toe thrust, and a flank that contains a rounded overhang. In addition, the model has several fault planes, 5 sand bodies, some charged with gas, and a geopressured shale sheath. The overthrust model has a complexly thrusted sedimentary succession that is structurally decoupled from the underlying basement. The basement contains an earlier extensional and rift sequence. The sedimentary succession contains a central thrust-faulted anticline with external monocline and flat-lying (undisturbed) zone. Some sedimentary layers contain channels and crevasse splay lenses.

The goals of the numerical modeling effort were decided through carefully chosen compromises derived partly from a survey of the expected user community and from the computing resources that were realistically available. The first decision was to emphasize structural aspects over fluid / lithology and stratigraphic aspects of the problem. Several practical considerations lead to a decision to limit the modeling to the constant density, acoustic case. First was the amount of time needed to design the geologic models. After specifying the position and shape of the important features in the models, specification of full elastic parameters would have consumed much more time than was available to the participants. Second was the amount of computing resources available. Computing the fully elastic response would have required several times the effort needed to compute the acoustic response. Third was the amount of storage needed to archive the synthetic data after it was computed. Storing the data set and providing for retrieval of arbitrarily selected portions from it were challenging tasks.

The acoustic data set produced by the SEG/EAGE modeling effort was intended to provide a challenging test of 3-D seismic imaging and other seismic processing methods. The data set is being used by many industrial, governmental, and academic researchers.

Why an Elastic Modeling Initiative?

Interpretation of 3-D seismic data has become more difficult as exploration plays have turned to more complex structures and settings. Separating real events from artifacts is increasingly important, yet extremely difficult. Extracting reliable images of structures beneath arbitrarily shaped salt bodies or highly thrusted areas is only beginning to be possible, but is critical for continuing exploration success. Greater amounts of 3-component and 4-component seismic data are being acquired to expand the range of situations in which seismic methods are useful. Compared to single-component data, however, multi-component data contains effects that have never been of concern before.

Modeling is an important validation tool for all phases of data gathering and analysis. The need to understand elastic and converted wave effects requires that this modeling effort use 3-D elastic wave propagation. Elastic modeling increases computing needs dramatically, but two factors mitigate the increase somewhat, compared to the early 1990's when the SEG/EAGE project decided to use an acoustic modeling code. First, greater computing resources are available, and at a lower cost than 5 years ago. Second, we propose to compute elastic responses only from portions of the models in order to make this initiative successful.

Several 3-D elastic wave modeling codes have recently become available (Cheng et al., 1994; Larsen and Schultz, 1995; Olsen et al., 1995). But, before undertaking a massive effort requiring tremendous resources it is desirable to undertake a feasibility project. This would define models with reasonable elastic parameters and a realistic survey geometry (such as an ocean bottom four component survey). Then the synthetic elastic wave response in portions of the model would be generated. By focusing on specific problems in which elastic waves may be important, the elastic modeling initiative seeks to extract the greatest benefits from the resources available.

The elastic model data obtained from this initiative will complement the larger and fuller SEG/EAGE acoustic model data set. The scope, objectives, and benefits of this Elastic Modeling Initiative are further described below, and in two companion papers, which describe the results of 2-D elastic modeling and imaging (Kessinger et al., 1998) and the 3-D elastic modeling code that will be used (Larsen and Grieger, 1998).

Objectives

The main objectives of the elastic modeling initiative are to test and evaluate elastic wave effects, particularly on imaging of complex structures. The initial work will focus on salt related structures. Depending on success with salt models, the initiative may be extended to other structures later. The initiative will conduct a feasibility study on the resource requirements, technical issues, priorities and implementation plan for a major elastic modeling undertaking. Technical issues include model parameter definition, geological considerations, and data acquisition geometry problems. Further, the initiative will attempt to put processing, imaging and reservoir modeling applications in a proper perspective regarding the reliability and interpretation of 3-D elastic wave (and converted wave) fields and the respective seismic images. These problems have been highlighted by recent studies of elastic wave effects (Ogilvie and Purnell, 1996; Kessinger and Ramaswamy, 1996).

Selecting elastic model parameters will be more important and difficult than selecting acoustic model parameters was for the SEG/EAGE acoustic modeling effort. In addition to choosing appropriate P wave velocities, density and shear wave parameters will have to be chosen. The SEG/EAGE modeling project assumed that density was constant throughout the models.

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Choosing meaningful shear velocities and densities will require significant work using the available rock physics data and empirical relations. Plausible model parameters will depend on the age of the sediments, their burial depth, charging mechanism, fluid properties, present depth, pressure and temperature. An element of the feasibility study will focus on whether it is reasonable to include the effects of anisotropy in the ultimate model.

The geologic problems of concern include the effect of dip of salt interfaces on wave amplitudes, and use of elastic and converted waves to improve velocity analysis. It may be possible to mitigate some of the effects of interface dip through changes in acquisition parameters.

Problems of data acquisition include the choice of optimal offsets, use of towed cables compared to ocean-bottom and vertical-array cables, and the problems and benefits of recording multiple receiver components (3-C or 4-C).

For processing and imaging, among the questions to be studied are what circumstances improve or degrade the effectiveness of elastic and converted waves in improving images, what adaptations to traditional processing methods are needed, and how to suppress multiples without also removing elastic or converted waves.

Approach

This initiative will be undertaken as one of several tasks of an existing research project, which is a collaboration between the oil and gas industry, universities, and national laboratories ("Testing Advanced Computational Tools for 3-D Seismic Analysis Using the SEG/EAGE 3-D Model Data Set"; see House et al., 1996). The initiative will be carried out as a collaboration among industry participants, universities and national laboratories. Technical leadership will be provided by an industry liaison, with organizational leadership provided by the national laboratories. The industry liaison will be essential for providing technical guidance and facilitating communications among the industry participants. Funding for this initiative will be provided partly by the U.S. Department of Energy, through the existing research project, and partly through in-kind contributions from the industry participants.

Given the enormity of possible problems that can be studied, the initiative will start with a feasibility study to demonstrate the usefulness of 3-D elastic modeling, and estimate the scope and resources that would be needed for a fuller study. This feasibility study will focus on a relatively simple model that demonstrates some of the most important elastic wave effects. Depending on the success of the feasibility study, additional resources will be sought to expand into a fuller effort.

The feasibility study and the fuller study will follow a similar procedure. First will be to define a geological model that demonstrates problems of interest. Next, 3-D elastic model data will be calculated from the model. Depending on the size and complexity of the model, data may be calculated from only a portion of it. The elastic model data will be shared among the participants. The most important step will be imaging or other processing of the model data and evaluation of the importance of the elastic wave effects.

Part of the feasibility study will involve comparison of elastic model data with acoustic data from the SEG/EAGE data set. This comparison will not be as extensive as the validation effort done by SEG/EAGE project, however. That validation effort was important for the reliability and integrity of the large SEG/EAGE model data set, since computations were carried out on several different computing platforms.

The SEG/EAGE modeling project spent considerable time designing the salt and overthrust models. They are large models that realistically represent complex, but geologically plausible, exploration targets. This elastic modeling initiative will design simpler models in order to focus on some specific problems or situations in which elastic wave data can make a crucial difference.

A greater amount of computing power is more readily available now compared to when the SEG/EAGE project was started, about five years ago. Further, the moderate-scale parallel computing systems that have become common today do not require major modification of codes to run efficiently, and relatively small systems now have as much computing power as the large Massively Parallel Processing (MPP) systems of five years ago.

Providing storage and retrieval for the SEG/EAGE model data set has been a major challenge, mainly because of how large the data set is (several Terabytes total). This elastic modeling initiative will be producing much smaller model data sets, and less effort will need to be devoted to storing the data sets and making them available to participants.

Conclusions

Elastic wave modeling is an effective method for testing and validating the effects of elastic and converted ways in seismic data. The importance of better understanding of elastic wave and converted wave effects is underscored by the increasing need to reliably image and estimate reservoir parameters from seismic data in complex 3-D structures. Increasing interest in multi component seismic data also will require greater understanding of 3-D elastic wave effects. An elastic modeling initiative has been started to study these effects in a range of models, acquisition parameters and processing approaches.

Acknowledgments

Many of the issues involved in this elastic modeling initiative were posed during a workshop at the 1997 Annual SEG meeting, which focused on the studies that have been done with the SEG/EAGE model data set. Many attendees encouraged extending the modeling effort to address issues of elastic and converted waves. The direction and guidance of the industry participants has been an important factor in the initiation of this new modeling effort, and we wish to acknowledge their encouragement and insight. We also appreciated the comments and suggestions of Fred Aminzadeh. This work was partially funded by the U.S. Department of Energy, Office of Fossil Energy, through contract W-7405-ENG-36.

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